Y-balance test performance and leg muscle activations of children with developmental coordination disorder

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Running head: Balance and muscle kinetics of children with DCD

Abstract

This study aimed to compare Lower Quarter Y-Balance Test (YBT-LQ) performance and its leg muscle kinetics between children with and without developmental coordination disorder (DCD) and investigate the association between YBT-LQ performance and muscle kinetics in children with DCD. Forty-eight children with DCD (37 males and 11 females) and fifty-one children without DCD (32 males and 19 females) participated in the study. Leg muscle kinetics were measured using surface electromyography when performing the YBT-LQ. Children with DCD exhibited an overall lower YBT-LQ scores than the controls. They had a lower peak gastrocnemius medialis activation for YBT-LQ posteromedial direction and a shorter duration for the muscle to reach peak torque for YBT-LQ anterior direction. No relationship was found between YBT-LQ performance and leg muscle activations in children with DCD. Children with DCD exhibited a less competent YBT-LQ performance with atypical neuromuscular control.

Keywords: developmental dyspraxia, postural stability, neuromuscular control, dynamic balance

Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental condition where around 6% of children are diagnosed with it (American Psychiatric Association, 2013). Children with DCD are characterized by deficits in balance or postural control which affect their motor performance (Geuze, 2005; Fong et al., 2015). Dynamic postural control requires sustaining body positions throughout motion to preserve stability. For voluntary movements, maintaining balance relies partly on the ability of postural muscles to adapt to changes for anticipatory adjustments (Pollock, Durward, Rowe, & Paul, 2000). These neuromuscular and anticipatory postural adjustments are typically present in children between ages 6 and 7 years (Assaiante, Mallau, Viel, Jover, & Schmitz, 2005) but are impaired in children with DCD who demonstrate poor proximal stabilization and muscle activation inconsistencies (Jover, Schmitz, Centelles, Chabrol, & Assaiante, 2010; Geuze, 2005).

Dynamic postural control is required for normal daily activities (e.g., locomotion and sports activities). Unlike static balance, dynamic balance emphasizes feedback control (i.e., postural control that occurs in response to sensory feedback from an external perturbation) and feedforward control (i.e., postural responses that are made in anticipation of a potentially destabilizing voluntary movement) differently which makes it more challenging (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). Assessment of dynamic postural control is necessary to evaluate the functional postural stability and performance in daily activities in children with DCD. For example, the Star Excursion Balance Test (SEBT) measures dynamic balance performance which requires the participant to maintain single-leg stance while reaching one of the eight directions with the remaining lower limb (Kinzey & Armstrong, 1998). However, not all eight reach directions are fundamentally required when assessing for functional deficits (Hertel, Braham, Hale, & Olmstead-Kramer, 2006). The Lower Quarter Y-

Balance Test (YBT-LQ) is a simplified version of SEBT reducing it from eight to three reach directions (Plisky et al., 2009). It is a valid and reliable test for assessing dynamic balance performance in children population (Faigenbaum et al., 2014).

Dynamic postural control requires intricate coordination of muscle activations that are direction specific (Norris & Trudelle-Jackson, 2011). To the best of our knowledge, only two studies have investigated the muscle activation patterns during SEBT in healthy adults and the results were inconclusive (Norris & Trudelle-Jackson, 2011; Earl & Hertel, 2001). We postulated that YBT-LQ may be a better dynamic balance test for children with DCD given its simplicity, good validity and reliability (Faigenbaum et al., 2014). Although previous study revealed that children with DCD had delayed muscle activation patterns during standing postural control (Geuze, 2005; Fong et al., 2015) and are more prone to muscle fatigue (O'Beirne, Larkin, & Cable, 1994), there are no studies to date indicating the presence of any atypical muscle activation patterns in dynamic situations (e.g., during the YBT-LQ). Comparing YBT-LQ performance and muscle kinetics between children with and without DCD can provide insight into their dynamic balance performance and the underlying neuromuscular mechanisms associated with such performance.

The objectives of this cross-sectional study were to (1) compare the YBT-LQ performance and the lower limb muscle activation patterns between children with and without DCD, and (2) investigate the associations of YBT-LQ performance and muscle activation patterns amongst children with DCD. We hypothesized that children with DCD would exhibit significantly different YBT-LQ scores and lower limb muscle activations to the controls, and there would be a significant association with the YBT-LQ performance and lower limb muscle activation patterns in the DCD group.

Methods

Participants

A total of 200 children were recruited from primary schools in Hong Kong and our database of DCD participants between the period of March and August 2016 through invitations letters, posters and personal invitations. Ninety-nine volunteer children met the criteria to participate in the study and were willing to participate in the YBT-LQ. Forty-eight were allocated to the DCD group (mean age ± standard deviation = 8.03 ± 1.10 years; 37 males and 11 females) and fifty-one to the control group (mean age ± standard deviation = 7.82 ± 1.06 years; 32 males and 19 females).

The two-step method was used to determine children with DCD (Ferguson, Jelsma & Smits-Engelsman, 2013; Yam & Fong, 2018). First step involved mainstream primary school teachers selecting and referring children aged 6 to 9 years with fine and gross motor difficulties to us. To assess against the Diagnostic and Statistical Manual of Mental Disorder 5th Edition (DSM-V) (American Psychiatric Association, 2013), children were screened by the Movement Assessment Battery for Children, 2nd edition (MABC-2) (Henderson, Sugdens, & Barnett, 2007) in the second step. For criterion A of DSM-V, a score ≤15th percentile on the MABC-2 Test indicated motor skills below that expected for their age. For criterion B and C, teachers and/ or parents reported any motor difficulties interfering with daily living and onset of symptoms from early childhood, respectively. A series of questions were then given to parents to complete and rule out that motor deficits were not caused by neurological disorder or intellectual delay (criterion D). Furthermore, the DCD questionnaire 2007 version (DCDQ; Wilson, Kaplan, Crawford, & Roberts, 2007) was used to provide additional information regarding motor deficits of the child. Exclusion criteria included a history of significant lower limb injuries, received physiotherapy or related treatment in the recent 2 months, excessive disruptive behavior or emotional instability, inability to follow instructions, and disorders that may influence child's exercise ability or motor development (e.g., musculoskeletal, cardiopulmonary, visual, vestibular, somatosensory or neurological disorders). The inclusion and exclusion criteria were the same for the control group except having a MABC-2 score of >15th percentile.

Ethical approval was obtained from the Human Research Ethics Committee at the University of Hong Kong. Informed, written consent was obtained from the participants and their parents/ guardian prior to study participation. All experimental procedures were conducted by two physiotherapists in accordance with the Declaration of Helsinki (2013). All participants attended a single assessment session at the Physical Activity Laboratory at the University of Hong Kong between May and August 2016.

Outcome measurements

Demographics

Children and their parents provided information regarding demographics, medical history and exercise habits. Physical activity level (in metabolic equivalent (MET) hours per week) was determined by using the Compendium of Energy Expenditures for Youth (Ridley, Ainsworth, & Olds, 2008) with information such as exercise type, intensity, duration, and frequency. Body weight was measured by using an electronic scale (A and D, UC-321, Tokyo, Japan) and a stadiometer to measure height (seca 213, Seca, CA, USA). Leg length was measured by a measuring tape in supine position (from the anterior superior iliac spine to the inferior distal surface of the medial malleolus) (Coughlan et al., 2012; Plisky et al., 2009).

YBT-LQ and lower limb muscle activity measurements

Lower limb muscle activation patterns of YBT-LQ were measured by using circular Ag/AgCl bipolar surface electromyographic (EMG) electrodes (EMG sensor SX230-1000, Biometrics, Newport, UK), with an interelectrode distance of 2 cm. To reduce the skin impedance, participant's skin was prepped before applying electrodes to the muscle belly of the supporting (dominant) lower limb (rectus femoris, biceps femoris, tibialis anterior and gastrocnemius medialis) as location specified by Barbero, Merletti, and Rainoldi (2012). A foot pressure sensor (FS4 contact switch assembly, Biometrics, Newport, UK) was applied to the non-supportive leg at the mid heel and first metatarsal to register the start of the trial. EMG signals were recorded and amplified at a sampling rate of 1000 Hz with a bandwidth of 20 to 460 Hz (input impedance at $>10^{15}$ Ω and common mode rejection ratio >96dB) (Biometrics, 2012). The reference electrode (R506, Biometrics, Newport, UK) was located at the ipsilateral tibial tuberosity. All apparatuses were connected and secured to a DataLOG device at the waist level with adhesive tape.

Dynamic balance performance was assessed by using the Y-Balance Test Kit™ (Move2Perform, Evansville, IN, USA) to perform the YBT-LQ. The dominant limb was determined as the tested limb (i.e., the weight-bearing leg). It has been previously revealed that there is no significant difference between limbs in healthy participants during dynamic postural control task (Gribble, Hertel & Plisky, 2012). Moreover, unilateral recording of dynamic balance has been adopted in previous studies (Kang, Lee, Park, & Oh, 2015). A physiotherapist demonstrated the YBT-LQ standardized testing procedure referenced from the Move2Perform website to the participant. In brief, the participant stood on his/her dominant leg and reached in different directions using the non-dominant leg. Participants performed six practice trials for each reach direction to minimize the learning effects (Hertel, Miller & Denegar, 2000). The testing order was three trials in the anterior (AT) reach direction which was then repeated for posteromedial (PM) and posterolateral (PL) directions. The maximum reach distances for each successive trial was recorded to the nearest one decimal place to be averaged later. The trial was considered invalid if the participant (i) kicked the reach indicator to gain additional distance; (ii) stepped on the reach indicator for support; (iii) contacted the floor with the weight-bearing or non-weight-bearing leg; and (iv) fell or lost balance. Invalid trial recordings were discarded with the trial repeated.

YBT-LQ normalized scores

To normalize the YBT-LQ reach distance for comparison among individuals, the reach distance for each direction (AT, PM and PL) was divided by the leg length. The normalized mean reach distance was determined by averaging the normalized scores of the three successive trials. Composite score was calculated by adding the greatest reach of the three directions divided by three times the leg length and then multiplied by 100. A higher YBT-LQ normalized score indicates a better dynamic balance performance.

Lower limb muscle peak activation

Raw EMG data was collected simultaneously during the YBT-LQ trials and then post-processed using the Biometrics EMG analysis software for DataLOG version 8.51 (Newport, UK). The peak electromyographic root mean square (EMG_{rms}) value of each muscle during the YBT-LQ trial was selected from a 100-millisecond window. The muscle peak EMG_{rms} values of three successive trials for each reach direction were averaged and then normalized to the RMS value of the maximal voluntary isometric contraction (MVIC) of that muscle. The outcome was thus expressed as a percentage of MVIC (%MVIC) (Earl & Hertel, 2001).

Time-to-peak EMG_{rms} value of lower limb muscles

The start of the YBT-LQ trial was determined and registered by the foot pressure sensor on the non-weight-bearing limb from either the heel or first metatarsal. Time-to-peak EMG was determined by the duration (in ms) between the onset of the foot contact switch signal and the peak EMG_{rms} of each testing muscle.

Lower limb muscle maximal voluntary isometric contraction

Prior to the YBT-LQ, the MVIC of each tested muscle was measured for data normalization purpose. MVIC for each muscle was measured twice with a 1-minute recovery period in between. All tests were performed in a seated position (Dionisio, Almeida, Duarte, & Hirata, 2008) where the participant was instructed to remain his/her body still when exerting the maximal force against the manual resistance for 5 seconds. The highest mean value (RMS) during 1 second from the two trials was filtered and averaged to EMG_{rms} which was then expressed in %MVIC as explained above. The data was recorded to the DataLOG which was analyzed later by the Biometrics software (DataLOG version 8.51).

Statistical Analyses

Although there were no studies that investigated the YBT-LQ performance in children with DCD, previous studies have explored their balance ability and muscle activation patterns. A study conducted by Fong et al. (2015) examined the muscle activation patterns during unexpected perturbation in children with and without DCD. The effect sizes ranged from 0.6 to 0.9 where the effect size of 0.6 was subsequently used to calculate the sample size. Setting the statistical power at 80% with an alpha level of 5% (two-tailed), the minimum number of participants required to detect a between-group difference was 45 per group (objective 1). For the correlation analysis (objective 2), Geuze (2005) reported a significant correlation between EMG and postural control in children with DCD (r = 0.19-0.57). Thus, assuming an effect size of 0.60, a minimum sample size of 47 was required for the correlation analysis. Calculations were performed by using G*Power version 3.1.0 (Franz Faul, Universität Kiel, Germany).

The following statistical analyses were performed with the Statistical Package for Social Science (SPSS) 23.0 software (IBM, Armonk, NY). The Shapiro-Wilk test was used to confirm that the normality criterion was met for all continuous data. Demographic characteristics between the DCD and control groups were compared using the independent t-test (for continuous data) and chi-square test (for categorical data). The multivariate analysis of variance (MANOVA) was used to analyze the between-group differences with the YBT-LQ performance, peak muscle activation values and time-to-peak muscle activation. Muscle activities (rectus femoris, biceps femoris, tibialis anterior and gastrocnemius medialis) were measured for each normalized reach direction (AT, PL, PM) for the YBT-LQ performance. Pearson's correlation coefficients (r) were used to explore the bivariate relationships between YBT-LQ performance and muscle activations in children with DCD. Pearson's r values of 0.00–0.25, 0.25–0.50, 0.50–0.75 and 0.75–1.00 denote little, fair, moderate–good and good–excellent relationships, respectively. A two-tailed significance level of 5% was set for all the statistical analyses.

Results

Demographic characteristics

Participants' demographic characteristics are illustrated in Table 1. Between the two groups, it revealed no significant difference in age, gender, height, body weight, body mass index, leg length, physical activity level and EMG MVIC values of leg muscles. As expected, the MABC-2 percentile score and DCDQ total score were significantly different between the two groups ($p < 0.001$).

YBT-LQ performance & EMG-derived muscle activations

Table 2 illustrates the YBT-LQ performance, peak EMG_{rms} muscle activation and time-to-peak muscle activation patterns in the weight-bearing leg during YBT-LQ of the participants. The MANOVA revealed a lower YBT-LQ performance in children with DCD for all normalized scores (AT direction: $F_{1,98} = 16.357$, $p < 0.001$; PL direction: $F_{1,98} = 24.764$, $p < 0.001$; PM direction: $F_{1,98} = 19.706$, $p < 0.001$; composite score: $F_{1,98} = 27.421$, $p < 0.001$).

With respect to the EMG-derived peak muscle activation values (%MVIC) in the weight-bearing leg, only the gastrocnemius medialis for PM direction was significantly higher in children with DCD ($F_{1,98} = 4.905$, $p = 0.029$). The remaining peak muscle activation values were not significantly different between the two groups ($p > 0.05$). In terms of time-to-peak EMG_{rms} in the weight-bearing leg, only the AT direction revealed a shorter time to reach peak torque for all four muscles (rectus femoris: $F_{1,98} = 4.872$, $p < 0.030$; biceps femoris: $F_{1,98} = 7.036$, $p < 0.009$; tibialis anterior: $F_{1,98} = 5.283$, $p < 0.024$; gastrocnemius medialis: $F_{1,98} = 5.384$, $p < 0.022$) whereas PM and PL directions did not illustrate any significant between-group differences ($p > 0.05$) as shown in Table 2. Since 7 out of 48 children in our DCD group had comorbid autism spectrum disorder (ASD), sensitivity analyses were carried out by analyzing only children with DCD and without ASD. Comparable results were obtained (not shown).

Relationship between dynamic balance performance and leg muscle activations

Pearson's correlation analysis revealed insignificant relationships between YBT-LQ scores and muscle activation patterns in children with DCD ($p > 0.05$) (Table 3).

Discussion

Our results primarily supported our hypothesis that children with DCD had different YBT-LQ scores, peak muscle activations and muscle time-to-peak torque values in the lower limbs than typically developing (TD) children. Contrary to our expectations, no association was found between muscle activation patterns and YBT-LQ performance in children with DCD.

YBT-LQ normalized scores

Children with DCD had significantly lower YBT-LQ scores than TD children agreeing with a previous study (Ituen, 2016). However, Ituen's study focused on children with generalized joint hypermobility (GJH) where statistical analyses were not explicitly illustrated between TD and DCD group without GJH (Ituen, 2016). Children with GJH have a decreased trunk stability and since trunk movements influence postural control during YBT-LQ (Falkerslev et al., 2013), there may be discrepancies when comparing the performance scores. Furthermore, GJH has no significant association with motor performance (de Boer, van Vlimmeren, Scheper, Nijhuis-van der Sanden, & Engelbert, 2015) where assumption and comparison of results must be cautiously made.

Our findings supported previous studies that children with DCD had balance deficits and poorer postural control in bipedal standing (Geuze, 2005; Fong et al., 2015). Given that postural control ability in children with DCD is reduced with increased balance demands (Deconinck, Savelsbergh, De Clercq, & Lenoir, 2010), it is not surprising that our results revealed poorer YBT-LQ performance (that required good dynamic single-leg standing balance). Factors (i.e., muscle kinetics) that influence YBT-LQ performance should be examined to provide further insight into dynamic balance control in children with DCD.

Lower limb muscle peak activations during YBT-LQ

The peak EMG_{rms} values illustrated in our study were comparable to previous studies on muscle activity and SEBT. Rectus femoris from our findings (60.42% to 80.11% MVIC) were similar to values reported by Norris & Trudelle-Jackson (69% to 77% MVIC) (Norris & Trudelle-Jackson, 2011) but lower than values reported by Earl & Hertel (>100% MVIC) (Earl & Hertel, 2001). Biceps femoris, tibialis anterior and gastrocnemius medialis from our results (54.14% to 70.73%; 101.58% to 123.99%; 123.65% to 195.96% MVIC respectively) were higher than what was reported by Earl et al. (20% to >40%; >80%; >80% MVIC respectively) (Earl & Hertel, 2001). To date, there are no studies that investigated muscle activity for YBT-LQ, therefore the values of our study can only be compared with those from SEBT. Although both SEBT and YBT-LQ measure dynamic postural control, different measurement instruments were used. While SEBT uses tape measurers for indication, YBT-LQ requires the participant to apply actual pressure to the reach indicator on calibrated poles for each direction. Thus, the proportion of feedback and feedforward control for SEBT and YBT-LQ are postulated to be different (Coughlan et al., 2012).

Our findings illustrated a significantly higher gastrocnemius medialis peak activation during reaching in the PM direction. It is particularly interesting that gastrocnemius was also the only muscle that was not direction dependent for SEBT in healthy individuals (Earl & Hertel, 2001). We elucidated that a more pronounced gastrocnemius activation may be due to the increased muscle co-activation around the ankle joint to improve postural stability

(Geuze, 2003). The increase in shank stiffness decreases the ability to finesse the small compensatory ankle adjustments. Furthermore, PM reach direction was the most representative during the SEBT when identifying individuals with chronic ankle instability (Hertel et al., 2006). This suggests that AT and PL directions may not necessarily detect kinetic patterns that are present in the PM reach direction.

Muscle time-to-peak torque during YBT-LQ

The shorter duration in the muscle time-to-peak values for the AT reach direction is suggestive of a premature muscle activation in children with DCD. Examining the motor control mechanisms may provide insight. YBT-LQ challenges dynamic balance where feedforward control is dominant (Hatzitaki et al., 2002; Coughlan et al., 2012). When reacting to balance disturbances through the feedforward system, the sensitivity of the central nervous system may increase which thereby enhances the gamma motor neuron activity and firing frequency (Beckman, Thomas, & Buchanan, 1995). Children typically have a well-developed feedforward system at 10 years of age (Hay, Bard, Fleury, & Teasdale, 1991). However, children with DCD likely have a heavier reliance on feedback control and are under-developed in the feedforward components for anticipatory movement adjustments during YBT-LQ (Hay et al., 1991; Przysucha, Taylor, & Weber, 2008; Smits-Engelsman et al., 2003).

Our findings supported that children with DCD moved faster to reach a target with a compromised accuracy (Smits-Engelsman et al., 2003; Smyth, Anderson, & Churchill, 2001). This ballistic-like pattern may be a conservative strategy to shorten the duration in the subsequent deceleration phase (Przysucha et al., 2008) which provides them less time to make compensatory reactions to sustain posture. Maintaining a posture is harder than it seems for children with DCD when they are more prone to muscle fatigue (O'Beirne, Larkin, & Cable, 1994). This implies that during YBT-LQ, children with DCD may fatigue more easily than TD children. Muscle fatigue slows neural transmission and reduces mechanical efficacy which adversely affects balance ability (Gribble & Hertel, 2004; Basmajian, & De Luca, 1985). This ultimately reduces the efficiency of muscles to fine-tune during postural control (Gribble & Hertel, 2004; Jover et al., 2010). Of all the directions, AT is relatively more physically demanding with a larger knee-flexion moment to compensate for the trunk extension (Earl & Hertel, 2001). Consequently, PL and PM directions require less pronounced muscle activations and demands (i.e. quadriceps and gastrocnemius) where differences may not be as prominent (Earl & Hertel, 2001). We elucidated the premature muscle activation in children with DCD as a mechanism to compensate for the less efficient feedforward control performance.

Relationship between dynamic balance performance and muscle activation patterns

No relationship was revealed between the muscle activation patterns and YBT-LQ performance. Although previous studies have reported that hip and thigh muscles were positively correlated with YBT-LQ reach directions (Lee, Kim, Ha, & Oh, 2014; Wilson et al., 2017), muscle may not be the sole predictor of YBT-LQ performance. Perhaps, other factors such as joint angles, performance duration, trunk movements and upper extremity positions may influence balance ability which warrant further investigation.

Limitations

There were some limitations to this study. First, the concentric and eccentric phases of leg muscle contraction were not controlled during the YBT-LQ which may influence the muscle's maximum ability to contract and the time to reach peak torque. One should investigate the feasibility of using a metronome during the test (to standardize the speed of movement) for children with balance deficits in future studies. A second limitation was that muscle activity was only examined for the weight-bearing limb. Although, previous studies have only measured muscle activities of the supporting limb during SEBT (Norris & Trudelle-Jackson, 2011), YBT-LQ and SEBT use inherently different equipment. Thus, muscle activation patterns for the non-supporting limb using standardized procedures and instruments warrant further exploration. Finally, YBT-LQ measures dynamic single-leg standing balance control but by no means represents all spectrum of dynamic postural control. Generalization of results should be cautious when comparing to other activities. Nevertheless, the results of this study may benefit clinicians and therapists seeking to identify the dynamic postural control and kinetic profiles of children with DCD. Our findings could also inform the development of rehabilitative strategies for these children to improve their balance and neuromuscular control.

Conclusions

Children with DCD exhibited a less competent YBT-LQ performance with significantly different neuromuscular control than TD children. This was suggestive of a heterogenous feedforward strategy. Dynamic balance and neuromuscular control training should be included in the rehabilitation interventions for children with DCD with an emphasis to strike a balance between acceleration and deceleration phases of postural control movements. Further studies are necessary to reveal the relationship between muscle activation patterns with other factors and dynamic postural control in children with DCD.

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The authors declare no conflicts of interest.

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Tables

Table 1: Characteristics of the participants

	DCD (n = 48)	Control (n = 51)	p value
Age (years)	8.03 ± 1.10	7.82 ± 1.06	0.325
Sex			0.132
Male (n, %)	37 (77.1)	32 (62.8)	
Female (n, %)	11 (22.9)	19 (37.2)	
Height (cm)	126.77 ± 9.86	126.48 ± 7.83	0.874
Body weight (kg)	25.95 ± 7.20	25.54 ± 6.47	0.765
Body mass index (kg/m^2)	15.91 ± 2.79	15.74 ± 2.29	0.737
Leg length (cm)	65.09 ± 6.89	64.92 ± 4.95	0.886
MABC-2 (percentile)	8.90 ± 5.79	47.06 ± 19.15	<0.001*
DCD questionnaire 2007 total score	44.08 ± 12.29	56.33 ± 9.89	<0.001*
Physical activity level (Metabolic equivalent hours/week)	10.07 ± 8.42	14.51 ± 14.54	0.068
Comorbid conditions			
Attention deficit hyperactivity disorder (n, %)	3 (6.3)	5 (9.8)	
Autism spectrum disorder (n, %)	7 (14.6)	0 (0.0)	
Dominant lower limb			
Right (n, %)	46 (95.8)	49 (96.1)	
Left (n, %)	2 (4.2)	2 (3.9)	
MVIC EMG (µV)			
Quadriceps	1.30 ± 0.47	1.35 ± 0.51	0.621
Hamstring	1.39 ± 0.48	1.49 ± 0.39	0.301
Tibialis anterior	1.73 ± 0.59	1.77 ± 0.46	0.655
Gastrocnemius	0.93 ± 0.52	0.90 ± 0.55	0.720

Means ± standard deviations are presented unless otherwise specified.

*Significant difference at $p < 0.05$

DCD: developmental coordination disorder; MABC-2: Movement Assessment Battery for Children 2nd edition; EMG: electromyography; MVIC: maximal voluntary isometric contraction

Table 2: Comparison of outcome measures between the DCD group and control group

	DCD (n = 48)	Control (n = 51)	Mean Difference[a]	95% Confidence Interval	$F_{1,98}$	P value	Effect size
Y-balance test normalized scores							
Anterior	61.43 ± 9.73	69.26 ± 9.42	7.83	3.985, 11.668	16.357	**<0.001***	0.146
Posterlateral	85.78 ± 17.18	101.77 ± 14.61	15.99	9.612, 22.370	24.764	**<0.001***	0.205
Posteromedial	90.57 ± 17.55	105.83 ± 16.47	15.26	8.433, 22.075	19.706	**<0.001***	0.170
Composite Score[b]	79.31 ± 13.12	92.39 ± 11.60	13.08	8.121, 18.037	27.421	**<0.001***	0.222
Muscle peak EMG_{rms} (%MVIC) for Y-balance test							
Anterior							
Rectus femoris	69.72 ± 62.10	60.42 ± 45.88	-9.30	-31.085, 12.475	0.719	0.399	0.007
Biceps femoris	70.73 ± 43.27	69.63 ± 35.10	-1.10	-16.841, 14.647	0.019	0.890	0.000
Tibialis anterior	101.58 ± 58.29	105.59 ± 73.44	4.01	-22.722, 30.746	0.089	0.766	0.001
Gastrocnemius medialis	195.96 ± 136.91	151.91 ± 116.26	-44.05	-94.857, 6.747	2.963	0.088	0.030
Posteromedial							
Rectus femoris	65.32 ± 56.59	73.19 ± 47.56	7.87	-13.034, 28.775	0.559	0.457	0.006
Biceps femoris	54.14 ± 32.00	60.31 ± 39.25	6.17	-8.261, 20.602	0.720	0.398	0.007
Tibialis anterior	107.76 ± 72.82	113.35 ± 78.63	5.59	-24.882, 36.044	0.132	0.717	0.001
Gastrocnemius medialis	170.00 ± 129.22	123.65 ± 72.08	-46.35	-87.871, -4.808	4.905	**0.029***	0.049
Posterolateral							
Rectus femoris	80.11 ± 69.34	79.72 ± 56.21	-0.39	-25.611, 24.838	0.001	0.976	0.000
Biceps femoris	60.97 ± 36.22	63.70 ± 67.02	2.73	-19.134, 24.599	0.062	0.805	0.001
Tibialis anterior	123.99 ± 73.19	120.90 ± 78.33	-3.09	-33.555, 27.380	0.040	0.841	0.000
Gastrocnemius medialis	194.19 ± 131.75	144.91 ± 121.71	-49.28	-100.098, 1.542	3.705	0.057	0.037
Time-to-peak EMG (ms) for Y-balance test							
Anterior							
Rectus femoris	3.38 ± 2.09	4.67 ± 3.48	1.29	0.130, 2.460	4.872	**0.030***	0.048
Biceps femoris	2.78 ± 2.07	4.40 ± 3.67	1.62	0.407, 2.825	7.036	**0.009***	0.068
Tibialis anterior	2.68 ± 1.93	3.96 ± 3.33	1.28	0.174, 2.382	5.283	**0.024***	0.052
Gastrocnemius medialis	3.06 ± 1.99	4.21 ± 2.82	1.15	0.167, 2.140	5.384	**0.022***	0.053
Posteromedial							

Rectus femoris	3.59 ± 2.71	3.64 ± 2.47	0.05	-0.990, 1.085	0.008	0.928	0.000
Biceps femoris	4.22 ± 2.86	3.91 ± 2.43	-0.31	-1.369, 0.755	0.329	0.568	0.003
Tibialis anterior	3.32 ± 2.95	4.10 ± 2.20	0.78	-0.259, 1.815	2.215	0.140	0.023
Gastrocnemius medialis	3.17 ± 2.30	3.79 ± 2.62	0.62	-0.364, 1.618	1.579	0.212	0.016
Posterolateral							
Rectus femoris	3.43 ± 2.68	4.35 ± 3.53	0.92	-0.344, 2.188	2.088	0.152	0.021
Biceps femoris	4.11 ± 2.66	4.25 ± 3.69	0.14	-1.160, 1.438	0.045	0.832	0.000
Tibialis anterior	2.74 ± 2.46	3.75 ± 2.62	1.01	-0.009, 2.030	3.867	0.052	0.039
Gastrocnemius medialis	2.93 ± 2.46	3.78 ± 2.72	0.85	-0.198, 1.890	2.585	0.111	0.026

Means ± standard deviations are presented unless otherwise specified.

*Significant difference at $p < 0.05$

[a]Mean difference: control subtract DCD group; [b]Composite score = [(anterior + posterolateral + posteromedial) / (leg length × 3)] × 100

EMG_{rms}: $Electromyography_{root\ mean\ square}$; MVIC: maximal voluntary isometric contraction; df: degrees of freedom

Table 3: Relationship between dynamic balance performance and muscle activation pattern in children with DCD

	Y-balance test anterior score	Y-balance test posterolateral score	Y-balance test posteromedial score
Anterior time-to-peak rectus femoris	r = 0.157; p = 0.285	r = 0.116; p = 0.432	r = -0.035; p = 0.811
Anterior time-to-peak biceps femoris	r = 0.166; p = 0.261	r = -0.034; p = 0.817	r = -0.017; p = 0.910
Anterior time-to-peak tibialis anterior	r = 0.103; p = 0.486	r = -0.004; p = 0.976	r = -0.070; p = 0.638
Anterior time-to-peak gastrocnemius medialis	r = 0.093; p = 0.530	r = 0.276; p = 0.058	r = 0.006; p = 0.965
Posterolateral %MVIC gastrocnemius medialis	r = 0.049; p = 0.742	r = -0.122; p = 0.408	r = -0.027; p = 0.858

Note. r = Pearson's r value; p = p value

No significant correlations were found between Y-balance test scores and muscle activation values.